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# MODEL FOR DEFINING THE TRANSPORT DESIRE LINES GRID IN THE PHYSICAL PLANS OF COUNTIES

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Subject review

The basic task of the transport infrastructure planning within the physical planning documents is to ensure adequate availability to all facilities. In order to achieve theoretical and practical requirements for ensuring an adequate access to the transport attraction zones, it is necessary to choose quality methodology of defining connections to the focuses of development (attraction zones) and thus to establish adequate transport routes according to the levels and modes of transport. Based on the aforementioned, an adequate transport network is generated. This paper presents one of the possible models for defining the transport desire lines grid applied in the Physical Plan of the Primorje-Gorski Kotar County.

***Keywords:*** *land use –transport modelling, physical planning documents, transport desire grid*

## Model za definiranje prometne mreže linije želja u prostornim planovima županija

Pregledni članak

Temeljna zadaća planiranja prometne infrastrukture u okviru dokumenata prostornog uređenja je osigurati odgovarajuću dostupnost do svih sadržaja. Kako bi se ostvarile teorijske, a potom i praktične pretpostavke za osiguranje odgovarajuće dostupnosti do zona prometne atrakcije nužno je odabrati kvalitetnu metodologiju definiranja veza prema žarištima razvoja (zona atrakcije) te temeljem istoga utvrditi adekvatne prometne pravce po razinama i modovima prometa iz koje se potom generira odgovarajuća prometna mreža. U radu je predstavljen jedan od mogućih modela za definiranje prometne mreže linije želja primijenjene u izradi Prostornog plana Primorsko-goranske županije.

***Ključne riječi:*** *prostorno-prometno planiranje, dokumenti prostornog uređenja, mreža linija želja*

## 1 Introduction

Physical Plan of the Primorje-Gorski Kotar County (PPPGKC, Plan) was adopted in 2000. The structure of its development was very complex, and the development itself was extremely studious – it lasted for five years (initiated in 1995). At the very beginning, it was necessary to opt for the methodology of the Plan development. By analysing previously conducted spatial research for the preparation of physical plans of counties and based on personal empirical research, it has been found that the most appropriate method for the development of the Plan would be functional-nodal method. [1]

This method in its first step divides area according to its significance; it evaluates its sensitivity, and it establishes the basic centres of development and the connections between them. In this way, the basic guidelines for planning and land use are determined. Based on theoretical concepts established in this way, the concept of the Plan is determined and later elaborated into the final Plan. Functional-nodal method is a method that is used for creating a new Physical Plan of the PGKC (initiated in 2010).

From the aspect of transport engineering and transport planning, the methodology for defining the system of connections between the focuses (or centres) of development is particularly important; i.e. the manner in which they are theoretically connected, as well as establishing the basic transport routes together with transport network derived from them. In order to confirm optimality of the existing and planned transport network, a thorough revision of the entire transport structures of the PGKC has been conducted. In this way, some shortcomings in the existing road network were identified along with the need to supplement the planned network and to confirm the quality and usability of previous plans.

In this paper is given an overview of the basic theoretical assumptions of the land use-transport planning. Especially is analysed the problem of dividing the area to the transport zones (poles) and the model for establishing their connections. Through the presented theoretical model and applicable example implemented in the PPPGKC one of the possible solutions is proposed. The proposed and presented model defining the connections between the pre-defined poles of development and the way of formulating primary transport routes is consistent with the basic principles of both the transport and physical planning.

## 2 Basic principles of transport planning

Availability, mobility and safety are the basic aims of any transport system's development. Previous international experience shows that transport planners are primarily concerned with mobility and less with availability. Therefore, spatial effects, as a rule, are not analysed properly. However, from the physical aspect, the basic task of transport infrastructure planning, even within the framework of physical planning documents, is to ensure adequate availability of all facilities in the area. This initiates a more intensive spatial interaction between the transport zones regardless of their purpose.

The key to understanding urban entities lies in analysing spatial structures and interrelations of trade and function (purpose) of space. Spatial interaction here implies the nature and the size of destinations of urban movement of passengers or cargo. It takes into account the attributes of the transport system and land use factor, generated by certain area attractions. Interaction itself is directly determined by the level of accumulation of physical activities and by the demand for overall mobility. [2] It can be said that quality interaction between any two zones increases the level of availability and reduces the cost of travel (in time or money). If the immediate availability of the individual zones by roads with high level of service is ensured, it is expected that the changes in their content (purpose) would be initiated, or their attractiveness would be increased.

Planned demanding zones regarding transport are the source or attraction of a large number of trips. In order for a road or other transport facility to be properly functionally determined, it is first necessary to relate it with the purpose it has to meet. In doing so, the availability depends on the attractiveness of the location of the starting point (which is reflected in the level of access to other locations) as well as the location of destination (which is reflected in the level of access from other locations). The basic consideration of spatial interaction model is that the traffic flow is in the function of the starting point location attribute, the destination location attribute, and the attribute of the traffic path between the starting point and destination. Therefore, the basic formulation of spatial interaction model is as follows:

$$T_{ij} = f(V_i, W_j, S_{ij}),$$

where $T_{ij}$ presents the interaction between the two locations ($i$-starting point and $j$-destination). The measurement units may include the number of people, tons of cargo, traffic volume, etc. They also include the time (e.g. an hour, a month or a year). Very often this is linked with the capacity of the transport network and the ability to use different modes of transport. In doing so, the following terms represent the following:

$V_i$ – starting point attributes $i$. These variables are often used to express attributes of socio-economic nature, such as population, the number of jobs available, industrial development, or gross domestic product.

$W_j$ – destination attributes $j$. They use similar socioeconomic variables like the starting point attributes.

$S_{ij}$ – attributes of distance between the starting point $i$ and destination $j$. They are also known as transport forecasts. The variables are often used to display attributes such as distance, transportation costs or travel time.


**Figure 1** Availability as a connecting element of transport and purpose of space [3]

Since in this case the transport planning is an integral and indivisible part of physical planning, certain theoretical starting points arising from the theory of physical planning were adopted. According to [4], gravitational model is used in determining the interaction between cities, as well as identifying nodal regions and the hierarchy of nodal centres. It is based on the renowned theory of gravity set by J. Newton in the seventeenth century. His theory states that two bodies attract each other and that the force between them is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. In other words, the gravitational model measures the interaction between all possible starting point-destination pairs. The level of interaction between the two locations is measured by multiplication of attributes, which are then divided. Then the division is the square of the impact of distances resistance growth. It can be expressed using the following formula:

$$T_{ij} = k \frac{P_i P_j}{d_{ij}^{\ b}},$$

where $T_{ij}$ indicates the intensity of attraction; $P_i$, $P_j$ – the significance of the location of starting point $i$ and the location of the destination $j$; $d_{ij}$ – the distance or any spatial measure between the starting point $i$ and the destination $i$ and the destination $j$; $k$, $b$ – constants [5].

In order to conduct transport analyses, primarily it is necessary to identify the reasons for the trip, and to determine the patterns of participants behaviour in the transport process. The identification of these patterns, through the simulation of all the choices that may occur in the transport process, as opposed to the actual selection of individual transport users, can be carried out simultaneously and sequentially. If they are carried out simultaneously, then this option is simulated using direct models. If the selection is carried out in a consecutive and interrelated way, then the simulation is carried out using the sequential models. The data used in these models can be expressed at different levels of aggregation [6]. Data aggregation is the process of integrating multiple data that constitute a relative unit. Collection and processing of data on transport demand can be carried out at different levels of aggregation. Aggregation level of the model and the number of dimensions that transport demand is analysed on, essentially determine the course and the results of modelling. Data on transport demand can be collected and integrated according to multiple dimensions that can be mutually independent. The application of aggregate models requires data given the level of the starting point zone and destination zone. Simulating the choice of travelling using disaggregated [2] models assumes that the existing data is broken down to the extent of reported transport movements at the level of individual households or passengers. Four common types of models depending on the level of aggregation and data analysis are as follows: sequential aggregate models, direct aggregate models, sequential disaggregated models and direct disaggregated models.

With respect to the observed level of the physical plan and the data which transport planner uses to perform analysis of an area, it is evident that the transport modelling for the counties physical plans must be based primarily on sequential aggregate model.

The feature of aggregate models is that they collectively show the transport demand and transport movement between the defined zones, but no movement within the zone. The modelling process flows so that the observed area (e.g. state, region, micro-region, spatial unit, city, etc.) is divided into zones that have homogeneous characteristics and are suitable for the assessment of travels that occur or will be drawn into the observed zone. Due to the complexity of the network, only those links (bonds) that are highly utilized or are critical to the functioning and performance of the system are introduced into the model.

When we talk about the sequential aggregate models, the sequence attribute means that the stages are performed relatively independently, one after the other, in the appropriate sequence. The main characteristic of staged/sequence forecasting model of transport system is that the decision to travel is simulated through successive stages (steps), where the results of previous stage present inputs for the next stage. In literature and in practice, the most present is the traditional four-step model developed for forecasting travel in urban areas. Basic steps in a classic four-step model are: creation of a trip, spatial distribution of trip, modal distribution, and trip assignment.

## 3 Model of transport network in the physical planning documentation

The model of transport network is made up of a series of entities, segments of the transport network (links/nodes) that are limited by nodes, transport zones (poles/focuses of development). Each entity contains attributes such as length of connections, transport systems that travel through them, their capacity, free speed on them, the number of lanes and their capacity, etc.

In the context of transport planning, defining transport zones and routes presents a fundamental precondition for the quality linking of spatial contents, and it is a critical segment of the mutual cooperation of spatial planners of different professions (especially urban planners and transportation planners). It is based on factors that affect the generation of transport demand, or otherwise directly affect the flow of transport on the planned road network.

### 3.1 Defining transport zones in the physical plans of counties

In order to determine the spatial distribution of trips that occur in a particular area, it is necessary to divide it into the transport zones. Transport zones are less spatially geographic, demographic and economic homogeneous units of an area. They serve as aggregate and address areas of final travelling points in transport modelling. Moreover, they are used for easier and clearer presentation of the results of analysis and modelling. A typical transport model includes only interzonal transport, and ignores intrazonal transport [7].

From the standpoint of physical planning, transport zones are predefined by basic parameters of elaboration depending on the level of physical plans, in our case at the lowest level identified as a spatial unit. Plans of higher levels generally strategically define a particular use of land (potential transport zone), which is later sized and determined in detail by the preparation of physical plans of lower levels. Therefore, the term transport zone is, in fact, determined by the level of physical planning documents which it refers to.

In order to obtain as faithful and detailed picture of the transport movements as possible, in the phase of land use-transport modelling, it is required to work with a relatively large number of zones. Otherwise, a certain proportion of transport is "lost" or is unrealistically presented in the nodal points of the network. This kind of work on a land use-transport modelling enables setting the planned road network, determines its function (road category) and the optimal network design.

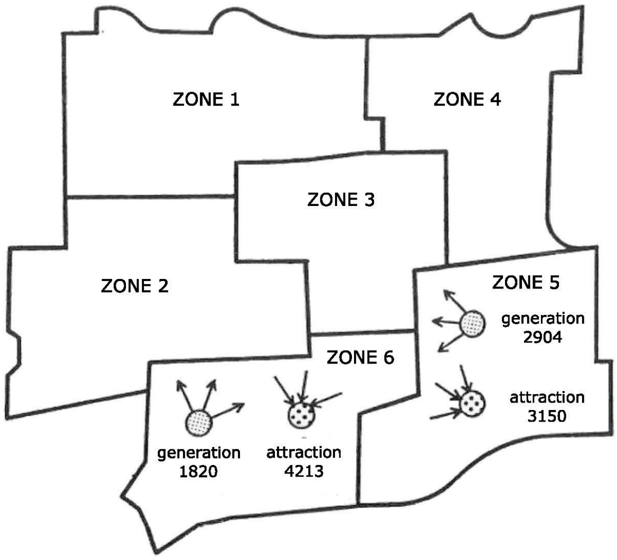


**Figure 2** Expected number of generated and attracted trips in a certain area [8]

Planned defining of spatial units is determined by the characteristics of the space, while the dotted determining of the focuses of development (of settlements, economic, tourist, sports and other zones) actually represents the input parameter for the quality sizing of transport routes which the mentioned focuses are connected with. It is known that different functions of space have different degrees of travel generating and that transport connectivity varies by the type and frequency of certain facilities, which is especially important when creating transport projections.

In general, a differentiation of an area is made into smaller portions of specific features, such as regions, units, sites, landscapes, etc., applying analytical (differentiation starts from large units (state, county, local government, etc.), which are divided into the small parts system) and the synthetic approach (regionalization starts with small spatial units which, based on similar characteristics, are grouped into regions).

It can be said that the territorial and functional divisions of space are the fundamental basis for structuring physical planning documents [2,4]. In addition to the analytical process used to determine the functional division of space, in everyday communication and collection and processing of data on space, the basis is the administrative division.

The first step of the functional-nodal method is the establishment of homogeneous spatial units and their ranking. The basic division of space begins with the region. The region is a planned category, which encompasses a wide range of area size, and is divided into several subgroups that are graded into the region (R), micro-region (mR), spatial units (SU), zones, etc. Spatial units are formed by the hierarchical pattern from larger to smaller parts, and are usually related to selecting the areas of the region. Depending on the level of spatial units these elements are changed or supplemented. Based on the functional units, the interpretation of gradation and capacity of activities and facilities in the area is performed.

**Table 1** Possible differentiation of space according to functional characteristics [9]

| Rank | Functional division | Functional characteristics according to public functions | Administrative division |
|---|---|---|---|
| | Macro-region - (MR) | | |
| I | Region - (R) | university, government, hospital, opera, etc. | county or counties, |
| II | Micro-region - (mR) | colleges and/or high schools, governmental branch-offices, a smaller hospital, theatre | district, municipalities, |
| III | Spatial Unit - (SU) | high school and/or elementary schools, local government, health station, community centre | area of one or more municipalities/cities |
| IV | Structuration inside the settlement | elementary school | local district |

Each SU was formed on the principle of unity of space according to basic and remedial criteria and has its own functional autonomy of the same rank. Then, it is necessary to perform the synthetic analysis with the basic selection of the area that occurs performing the area selection. In doing so, the areas that make a rounded natural unit are not divided into smaller parts. Anthropogenic area depending on the intensity and frequency of activities in area (economic activity, housing, recreation, etc.) are still being considered and selected into the SU of specific homogeneous characteristics.

After that, the sensitivity of area and buffer zones are determined arbitrarily depending on the size of the area, the number and accuracy of data, and the desired level of the area selection. The basis for the structuring of the sensitivity of an area is a natural system.

After establishing individual spatial units in rank and function, it is necessary to define their focuses (poles) of development. Poles are used to position the focuses of interest and activity within a particular area (R, mR, SU). The type of area or their interrelationship (rank) also determines the corresponding category, importance or the pole rank. Within the functional units that represent a homogeneous space, by positioning and grading the poles, the position and rank (importance) of the focuses of development are determined in order to form the network of central settlements.

Given the content and functions, the system of hierarchy of urban centres with different gravitational zones was developed. Spatial dimension of urban system can be analysed in terms of the size of the urban system and its topological characteristics. Size (spatial coverage) of urban system determines its fundamental gravitational field. The size of nodal region is in accordance with the functional significance or the centre size, which can be divided into: daily or local, regional, national and international.

Between the focuses of development, permanent and temporary migrations are formed, usually recognized between the concentrated urban area and scattered rural centre. All the directions of motion, no matter how mutual (reciprocal) they are converge from the surroundings towards the city. Hence the concept of polarization effect of the city on area. The size of the gravitational area depends on the size of the focuses of development and the functions they contain, which serve a nearby space. It is important to emphasize that the scope of gravity does not depend directly on the size of the city (population) but its functions. The more features and higher the level, the more gravitational zone continues to extend. Furthermore, the size of the gravitational zone depends more on regional functions, so-called centralization functions, than on their own urban functions. Thus for the size of the gravitational zone, crucial functions are those of government, retail, other rare services, while the industrial functions generally create an influential zone of smaller radius (mainly labour migration zones). Every single function generates its own influential zone, but the gravitational zone refers to the area around the city in which simultaneous impacts of all major functions are apparent. In the case of the Primorje-Gorski Kotar County, excluding the city of Rijeka, the gravitational zone of individual focuses of development is directly related to the functional space level they belong to.

Fundamental system of central places in physical planning is determined by the Physical Planning Strategy and Program of the Republic of Croatia. It identifies Central European and state developmental centre (the capital), macro-regional centres (which includes the city of Rijeka), larger regional centre (neither in the PGKC), regional centre (neither in the PGKC), smaller centres of development of stronger and weaker development (such as a stronger centre Crikvenica, as a weaker centre Delnice, Krk, Mali Lošinj and Rab), district centre (Čabar Vrbovsko, Ravna Gora, Novi Vinodolski, Malinska, and Cres), local centre (the seat of the local government). Especially emphasized are the development centres under the influence of the agglomeration of Rijeka, which were recognized as socio-economic urban regions that have different focal point importance because much of the central functions can be found in a more significant centre. These include Opatija, Viškovo and Matulji as smaller centres, as well as Kraljevica, Bakar, Čavle, and Kastav. Determining the focuses of development is directly related to the structural functional division of the county arising from the focuses of development.

By taking into consideration the earlier predefined structuration of focuses of development from the level of the state, their further elaboration through the analysis of several groups of data is possible. Economic and demographic indicators are the dominant parameters for the development of an area, in this case for the individual functional units. They are based on the data presenting the indicators of the previous period, current situation, and trends and perspectives. They are determined by the levels of functional units and interpreted in the context of physical planning parameters. **The fundamental question for structuring an area is: How many jobs should be provided due to the planned economic development and predicted demographic trends?** The basis for obtaining data is a recognition of the basic development trends (annual rate, targeted national income per household); the dominant economic sectors and the structure of the planned activity (industry, transport, energy, agriculture, forestry, fisheries); the planned rate of demographic change in structure, density and ethnic structure, with requisite extrapolation of the projection of working-age population; and, strategic features of the area (border areas, transportation routes). Protection of the area, which is a very strong indicator of specificity of a particular area, also belongs to the anthropogenic features. Based on these economic and demographic data, the network of settlements and approximate number and the structure of the planned population per settlement are determined as well as the data on jobs per functional unit – it suggests the gravitating number of the working population. This procedure creates elementary preconditions for structuring the poles based on which, according to the rank of centrality which it belongs to, a network of central settlements is formed. In this way, through a multi-layered process, which included all the relevant physical characteristics, the system of central settlements is determined at all levels, along with their interrelationship.

The order by relevance of cities or towns actually stems from the following indisputable facts: (1) that each place cannot contain all the functions; (2) that for those more rarely needed functions, the distance of their availability is enlarged; (3) it is natural and desirable to organize functions in the form of a pyramid, i.e. a higher rank contains all the functions of the lower ranks; (4) there is a minimum economic limit of opportunities functioning of certain activities and demand. Cities are the bearers of central functions. Therefore, functional field of gravity is shaped around them. In an urban system, each city has its own functional mass and its geographic position, while its potential functional significance consists of the internal and external mass which depends on the relative geographic location of the city compared to other cities.

In forming the settlements network, gradation must be made from the first level onwards. This means that the centre of a SU from various mRs is not of the same characteristics even though it is of the same rank. Therefore, based on additional evaluation, the analysis of centres within the same group is carried out. For the purposes of physical planning, when carrying out the analysis of central settlements, simple models containing the catalogue of representative central functions, are often applied. Central settlements according to the degree of centrality are determined in a way that one or more representative institutions from primary central functions are determined for each level. For the purposes of functional-nodal method, the Christaller model of gravitational radius of the central settlement area and the model of determining the central settlements by catalogue of central functions were used [6, 7].

### 3.2 Defining the transport routes in the physical plans of counties

A common trip classification is dividing trips into their starting points and destinations. In this way it is indicated that each transport movement has a beginning and an end, and the path that connects these two points. Spatial presentation of such a trip creation process is known as **desire lines grid**. Formal and functional purpose of space presents the group of relations with other uses of the space. Given that each of the land uses has specific requirements for transport, transport is the key activity factor in the zone and is associated with a specific land use. Therefore, by analysing the creation of trips, the relationship between the respective activities of the area and of transport movement is determined in order to use that relationship to estimate the prospective size of transport demand. This demand is usually expressed by the number of trip ends. End of trip is defined as the beginning or ending of a trip. Each trip, such as trip from home to work, has two ends – one that represents the starting point and another that represents the trip destination, or where one end is the origination and the other is the trip attraction.

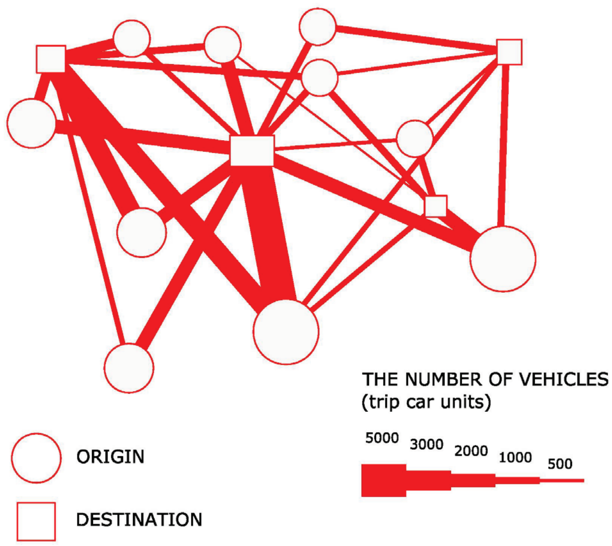


**Figure 3** Hypothetical desire lines grid [8]

After defining the desire lines grid it is necessary to well dimension the transport routes. When talking about transport routes, it is important to emphasize that each transport direction should, unless there are certain special features, meet the three conditions of equilibrium: linear, alternative, and time. [5] Therefore, it is necessary to establish a model of transport demand (trip model) written in the form of a travel matrix. At this stage, it is estimated how many transport entities will be forwarded to each destination. The forecasted transport flows, regardless of the unit of observation, are formed from the demand for travel within the observed gravitational area, where the total number of desired trips of a zone is distributed to all other zones in proportion to their feet of attractiveness. This indicates and confirms the usefulness of the gravitational models. [2,13] A significant piece of information that can identify specific areas of transport demand is the degree of urbanization. The way of land use was determined by its purpose until the level of spatial accumulation indicates its intensity and concentration. Most human activity, be it the economy, social or cultural programs, have multiple functions such as production, consumption and distribution. These functions can occur, depending on the accumulation of the space allocation, in urban areas. It is the urbanization that raises the question of location of industries, services and infrastructure development. The degree of urbanization is an indicator of how far the process of urbanization has come to.

When we talk about regional physical planning, the plan for the development of transport and other infrastructure follows the selection of space by the functional principle. Each level (R, mR, SU) determines the level (rank) of infrastructure. This is how one gets the national, macro-regional, regional, micro-regional network and the network on the level of spatial units. This analysis is required for all types of infrastructure, particularly for transport (road, rail, maritime).

By connecting the poles of the same rank an adequate network connection is formed. In this way, a very simple and rational matrix of poles and connections is formed – it has its origins in structuring (division) of space in a homogeneous whole.

## 4 Activities on the definition of the connections system in the Physical Plan of the Primorje-Gorski Kotar County

Different methodological approach in the process of planning and/or design of transport networks is possible, depending on their importance and category according to the adequate functional classification. County physical plans define, among other things, the primary network of corridors or routes and nodes selected to those of the state and those of county importance.

Planning the primary transport network of supranational, national or regional, or county significance has a critical impact on all events not only in the field of transport, but also in the land use (urban) as well as the overall development. In other words, the primary transport network forms the land use, economic, social and all other development of an area. Therefore, in the model, the improvement of transport services supply occurs as a basic stimulus (i.e. construction or reconstruction of the section) that has a decisive influence on all the other elements of the model (i.e. accessibility, land value, land use, trend, transport demand).

When planning a transport network of local significance the procedure is objectively different because the offer of transport services (i.e. building a network or section) is primarily the consequence of the need to satisfy the existing i.e. the planned land use with the required level of quality of transport service. In other words, planning, design and construction of transport network (or section) occurs subsequently in relation to the urban development and the demand for transport services. The local transport network is actually the consequence of zoning requirements. Therefore, at the level of physical plans of counties, it is determined in principle only, and its clearer articulation is made at lower levels of physical planning.

In order to establish a good quality basis for the new Physical Plan of the PGKC, an analysis of all the previous research was conducted for the purpose of development of strategic physical planning documents for the area of the Primorje-Gorski Kotar County. It has been confirmed that previously various analyses of land use-transport interactions were performed, which resulted in an unambiguous road network in the function of connecting the nominated focuses of development.

In order to confirm previous considerations on the development of the transport system of the PGKC, a thorough revision of previously planned transport network has been done. Using a developed model of forming connections and routes, the basis for this analysis was the newly created ideal connections network [10] that the ideal transport network later derived from, without taking into account the existing transport network. This will ensure the formation of an ideal network unencumbered by the present situation, which is often historically given and therefore not always ideal. By comparing thus obtained ideal network with the existing network enables the highlighting of real weaknesses in the transport network and thus highlighting the appropriate solutions for their removal.

In order to define the connection system, first of all it is necessary to determine the focuses of development of individual functional units (for transport engineers transport zones), which are then interconnected. It is important to emphasize that the system of connections has to be distinguished according to levels of connected centres. Output of these activities is a formed system of poles and connections that provides a starting point for further activities to the realization of the physical plan concept. It is possible that in the same route (in whole or partly on the arable land) more connections of different levels appear. In this case it is necessary to consider the density of the connection levels and, if necessary, during the formation of the transport routes network, to nominate one or more transport modes of generally higher level, with the aim of ensuring adequate road capacity. Therefore, it is sometimes possible to combine the networks of different transport levels in one transport link or even a road or rail connection.

Before defining the elements of the transport network, it is necessary to define their clear function in the transport system. By emphasizing the function of the single element of the transport system, the level of transport service, which is crucial for the fulfilment of this function, is determined. This means determining the level of infrastructure. After determining the relationship at all levels, it is essential to start planning the transport network, and the way in which the individual poles of development would be linked by rank and mode of transport; for example, whether the traffic of transit and local transport will be projected on the same roads. Then the access points are defined. Higher density of the access points on the roads of higher levels of customer service provides less congestion of local roads, but reduces the quality of service on the given road. Moreover, after determining the poles to connect, it is necessary to determine whether it is necessary to connect them using the direct connection or the connection via the other pole (bypass).

In practice, there is a compromise between the ideal and actual transport network conditioned by capabilities of their physical accommodation.

Furthermore, after the formation of the ideal network of connections, routes and roads, it is necessary to analyse the characteristics of each area. This particularly refers to the island areas and other areas of special national concern where, due to stimulating growth and development, a transport network that transcends the needs of the area but has a function of its revitalization. Thus it does not require a proof of its transport justification.

### 4.1 Theoretical problem of connecting the poles

When defining the desire lines, connections between the poles, it is necessary to determine the optimal connections that will ensure good availability to a particular traffic zone (pole). Designing a line of desire is a very complex task. First of all it is necessary to satisfy various interests. For example, a traveller will want a direct link between the poles while the investor, in order to reduce the cost, will force a centralized system with one line from the starting point of the higher level to each of the poles of the lower level within the same functional unit. Therefore, the primary role of the transport planner is when planning the transport network to determine the optimal variant of possible transport connections, which will increase the availability and reduce the cost of the network.

Given the demands of users and the configuration of space, transport network can be grouped into several basic types or schemes: radial scheme, radial-ring scheme, rectangular scheme, rectangular-diagonal scheme, triangular scheme, free scheme, etc.

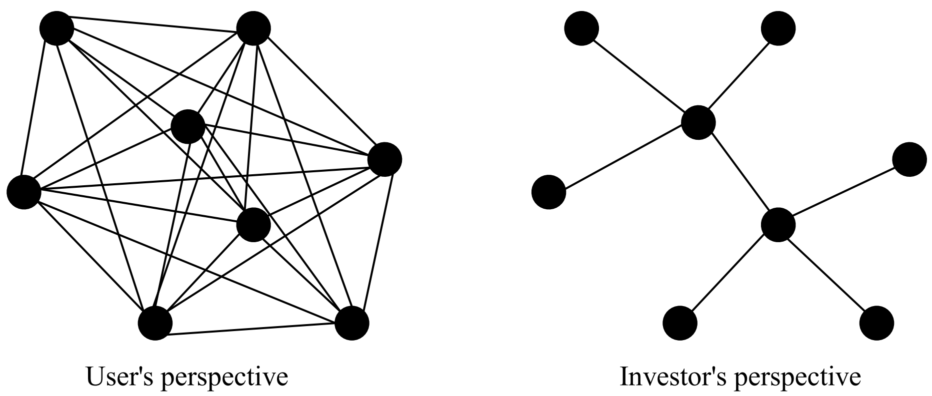


**Figure 4** An illustration of the difference in the perception of the optimal structure of the transport network from the perspective of a user and an investor [10]

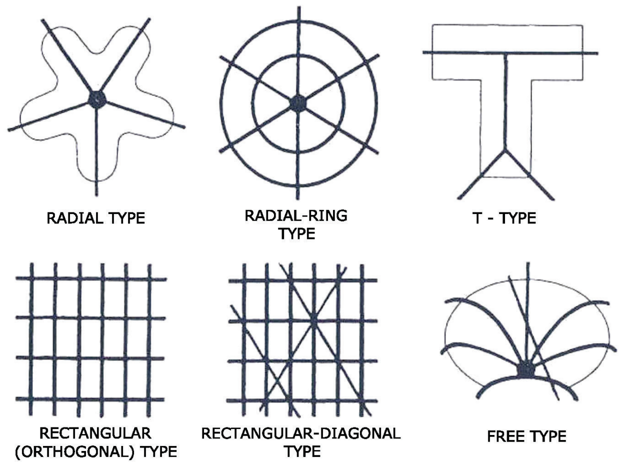


**Figure 5** Types of transport networks [11]

Each of these categories of roads (categorization is similar to that of air and sea ports, rail networks, pipelines, etc.) is special for its transport and technical characteristics. This is the reason that, considering its importance and role in the transport network, roads at different levels of transport services are planned with the purpose of optimally satisfying the transport demand.

In making decisions about the structure of the network, it is important to accept the demands of end users and to define quality transport infrastructure through open discussion. However, on a theoretical level, it is necessary to set specific settings which will by subsequent adjustments later lead to quality conclusions. If we accept the fact that the hierarchy of transport network is determined by the transport supply and demand, and taking into account that it is based on the gravitational model as the basis for the establishment of the system of connections, it is proposed that the transport network hierarchy is directly related to the hierarchy of poles. In this case, each level of the transport network provides connectivity to the poles of the same hierarchy and connectivity of the pole of lower significance with the poles of adjacent higher significance.

Defining the system of connections is primarily based on the need to connect the focuses of development of all levels. When developing the Physical Plan of the PGKC, there were nine levels established in the creation of the system of connections. Primarily, the significance of an area in the international system was determined. The imposed is traffic junction Rijeka (Rijeka port), which necessarily had to be connected to the international connections; then, the centre of the county is linked to adjacent centres of a higher level (capitals); connecting to the other centres of counties; and then to the micro-region centres. This is followed by interconnecting the centres of micro-regions and their connecting with the centres of spatial units. Furthermore, the sixth level in defining the system of connections is the need for interconnection of spatial units. Given the importance and role in the transport system (and the importance of the city of Rijeka not only as the centre of the county, but also as the centre of the macro-region) the network of focuses in the Rijeka ring, which must be connected to each other, was determined. The eighth step is presented by the highlights of the centre of local government units and their interconnection, and the establishment of separate construction areas of national and regional significance that should also be connected with the adjacent focuses of development.

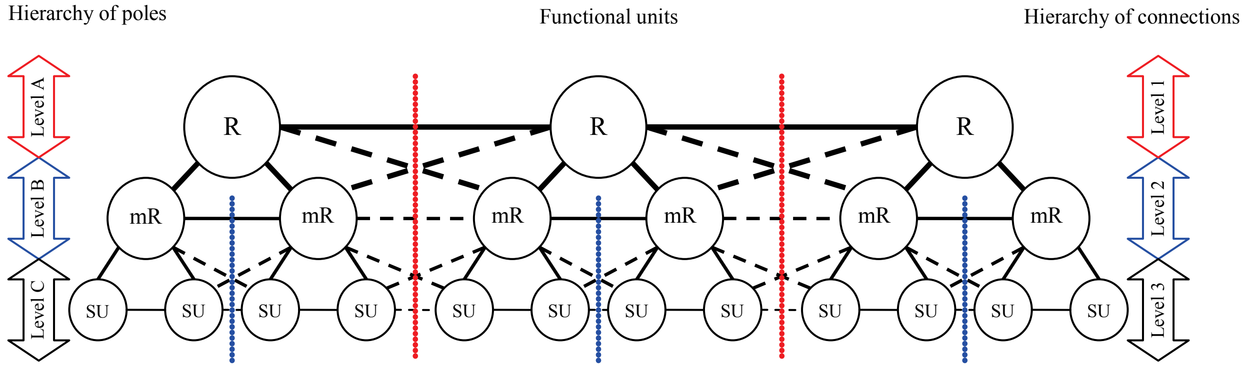


**Figure 6** The structure of the road transport network according to Schönharting and Pischner (1983) [10]

It is important to emphasize that for the definition of the system of transport routes the transport network will be generated from, on the level of the plan concept, the sixth level of elaboration of the connections system is used. The final level is articulated after establishing the concept of the plan or during the formation of the transport system, which is implemented in the draft of physical plan sent to a public discussion.

As noted before, the hierarchy of the transport network is primarily determined functionally. However, in urban areas, there is a strong tendency to integrate transport connections of different levels into a single road. It is clear that the nodes of motorways in urban areas are set in a denser way than in most rural areas. Therefore, an integrated hierarchy of networks can be attractive since it reduces the occupation of valuable urban area and thus the investment in the network. By using the roads of higher level, the trips of medium and short duration normally serviced by networks of lower levels will theoretically gain higher speed and quality; the number of these trips on a network of high-service level will significantly increase. Such traffic load will affect the level of transport service of users of long trips, and this would actually provide them with lower quality transport service than the one primarily desired when designing the network. These phenomena are common and often require considerable attention. Very often the solution is found in "artificial" creation of bypass roads which normally ensure unimpeded transit, while a road of high-service levels with denser nodes in urban areas actually becomes a road in the primary function of the urban area.

**Table 2** The relationship between connections with the structure and the level of transport route

| Level | Connections between the poles | Level of the transport route and modes of transport network |
|---|---|---|
| 1. | International transport connections | Motorways, fast roads + high speed/high efficiency railways (of international significance) or international sea lines |
| 2. | National transport connections | Motorways, fast roads, state roads, national railway connection, national sea lines (fast shipping and ferry) |
| 3. | Connections of the county centres | State level |
| 4. | Centre R-centre mR | County level |
| 5. | Centre R- centre SU | County level |
| 6. | Centre mR- centre mR | County level |
| 7. | Centre mR- centre SU | County level |
| 8. | Centre SU- centre SU | County level |

After establishing lines of desire (connections) between the focuses of development (poles), transport planner approaches to define a hierarchy of transport routes according to established levels of connections.

Basically the hierarchy of routes is fully complementary to the hierarchy of connections. However, if several connections of different levels are defined on one transport route, their adjustment is required. Graphic displays of routes, even though still on the level of solid lines, are generally placed in the area taking into account the available data about the area (land/sea, etc.).

In order to derive the transport routes from the established connections, clear relations between them should be established; it is necessary to determine the exact ranking of transport routes in relation to the level of transport connections. Preliminarily, the method of identifying the transport routes from the established system of connections is determined. Since in the physical plan design, as a rule, there is no implementation of special transport studies, transport engineer must necessarily use the available data, established for the physical plan. One of these data is the method of determining the matrix of the trip, i.e. determining the method of dimensioning of the transport network levels (resulting from the based level of transport routes). It is clearly established that the level of connection is directly determined by the level of the pole which it is directly connected to. If a connection is established between the poles of different levels, its level is identical to the higher level of the pole. Transport route is then determined based on the established transport connections and retains their level. In case that more than two transport connections are found on the same corridor, the additional transport routes are formed (taking into account the rule that one route is made by a maximum of two connections). Here, as a rule, the transport routes are united by connections in pairs according to the hierarchy, starting from higher to lower levels. Then the significance of the transport route is identical to the (higher) level of transport connection.

The underlying assumptions when defining transport routes within the Physical Plan of the PGKC [14] were conditioned by primary and additional criteria for their determination. Basic (transport) criteria were as follows:

1. with the Physical plan of a county, the international, state and county road networks are articulated,
2. cargo port of particular international interest for Croatia is primarily serviced by maritime/rail connection,
3. connection with state capitals must be ensured with a higher service level roads and with as many sectors of transport as possible (road/rail/etc.),
4. all connections to the poles (focuses/zones/facilities) are least consistent with the lower level of the pole that are connected with,
5. for connecting the island SUs, every connection should be articulated through road and sea route (with the aim of quality affirmation of islands, each defined transport route must be road (including ferries) and maritime (fast shipping lines, etc.),
6. transport routes can be connected with transport routes of the same or first adjacent levels.

The identified additional criteria are as follows:

1. The basic network of transport routes overlaps with the sensitivity map (areas where construction is forbidden are to be avoided), connections that pass through the level I (whether also II) of sensitivity are achieved by connecting to the nearest transport connection of higher level (connection Rijeka-Čabar through Risnjak),
2. large urban centres (overly suffocated by daily transport migrations) should be maximally protected from transit traffic (transit routes should be formed in bypass),
3. all border crossings at national level are connected with roads at state level,
4. ensure the ring structure of the transport connections at all levels,
5. in case between two zones of the same level there is a need to connect, and one (both) of them are on the route of the connection which is higher by two or more levels, the transport connection will be formed in such a way as to ensure immediate access to the nearest point of the transport route obtained from the connection of higher level to the transport zone,
6. in areas where transport connections overlap, a higher level of transport network can also be defined, and from the pole in which they divide, the route of the level equivalent to the connection is continued,
7. basic transport network of an island is of state significance.

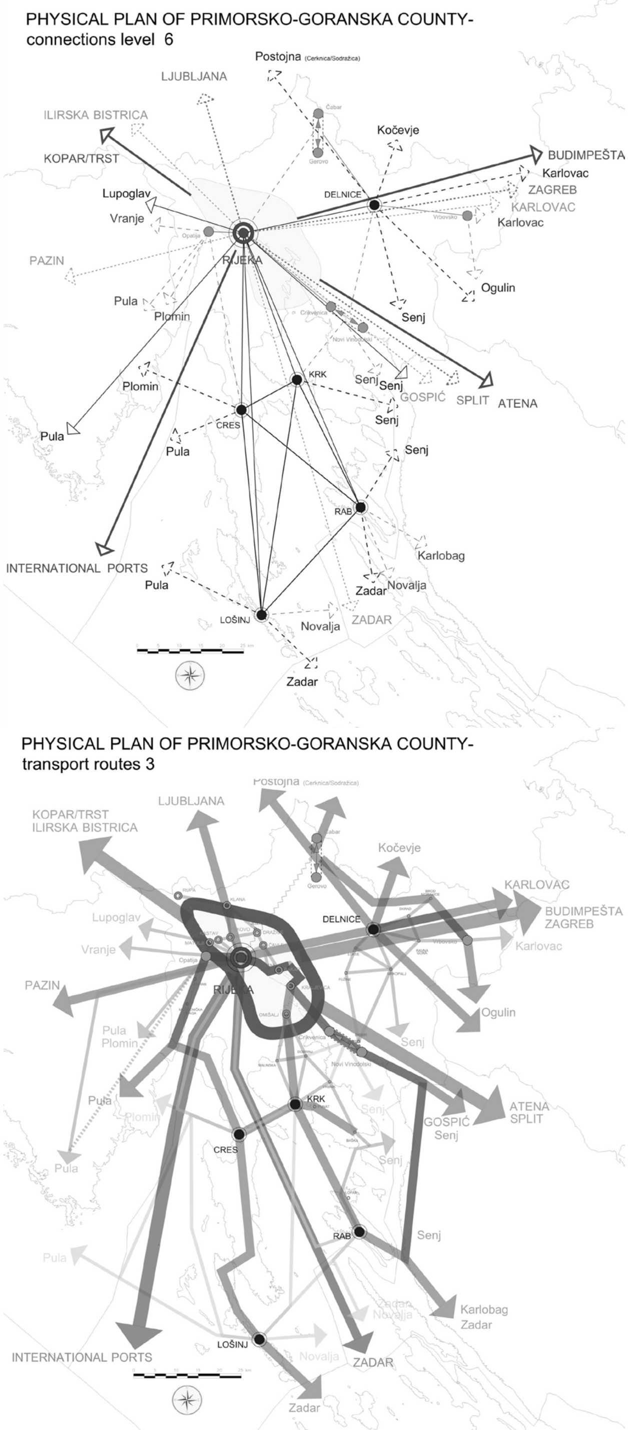


**Figure 7** Formed connections and established transport routes formed based on them, for the purposes of preparation of the Physical Plan of the PGKC

Transport routes established in that way overlap with the plan of higher labor (in our case, the Physical

Planning Strategy and Program of the Republic of Croatia), and the possible need for amendments or re-categorizations of individual routes is identified. It is followed by a comparison with the existing situation of the transport infrastructure, that is (if any) the applicable physical plan of the county. Through discussion and consultation, the suggestion of the transport network for the concept of the Plan is determined.

This established the basic network of transport routes that should be supplemented regarding the outputs of defining the network of settlements and the separate construction areas that must be accepted by the Plan. Generally, these activities are carried out after defining the concept of the Plan and the amendments of the transport network are made in graphics supplements adopted after a previous discussion (taking into account that all construction areas that are shown in the plan need to have the infrastructure connections). The rule is that certain isolated construction areas are connected to the transport network of the rank they belong to. Also, it is necessary to take into account that for each network of roads which may be expected to be in the collection system the possibility of alternative roads (out of collection system) is to be provided. This is particularly present and necessary in defining alternative routes for motorway networks or fast roads that are included in the collection system.

This is followed by the supplementation of the network of county roads so that the county centre and the centres of local government units (which are included in the graphics) are interconnected with county roads.

Significant roads within the area are then nominated as county roads – they are the connection between the city or urban parts with the state roads, as well as connecting roads that link the state and county roads with sea and river ports of county interest; airports; railway stations; freight terminals; tourist and recreational sites; sites and buildings registered in the national registry as a historical-cultural or natural heritage; settlements with more than 300 inhabitants, with the distance of the beginning of the settlement from the classified road being more than 500 m; and interstate road border crossings.

Thus defined transport network also makes the transport network being listed in the draft of a physical plan or the proposed plan intended for public discussion. After the public discussion and received comments, fine calibration of the transport network is performed and the physical plan is completed.

### 4.2 Application of graph theory in defining the system of transport connections

To define the connection to the focuses of development or defining the transport network of desire lines the graph theory can be used. Graph can be used to describe a model of a real system, such as the centres connected by transport connections.

Graph can be thought of as a family of points called peaks or nodes, along with the conjunctiva between nodes called arcs. Mathematically, a graph can be defined as the set $V$ with relation $R \subseteq V\times V$ and is written as $G=(V, R)$. The elements of the set $V$ are marked as $v\in V$ and they are named peaks or nodes of the graph, and the elements of the relation $R(v_i, v_j)\in R$ are named arcs of the graph. Frequently this is written as $G=(V, L)$, where the notion of binary relation is bypassed and with $L$ it marks the set of arcs, where each arc $l$ is the set pair $(i, j)$ of different nodes $i$ and $j$. It is appropriate to write $l=ij$, instead of $l=(i, j)$ [12]. For example, a set of focuses in the Primorje-Gorski Kotar County and a set of pairs of these focuses that are directly related to roads, make one graph.

Matrix calculus is a suitable device for the treatment of various problems with graphs. Let us say the given sets are $V=\{v_1, v_2,\ldots, v_m\}$ and $L=\{l_1, l_2,\ldots, l_n\}$ and one binary relation $R$ in the set $V\times L$. Binary route can be joined by incidence matrix. For every binary relation $R$ in the set $V\times L$ the incidence matrix is defined as $S_{V,L}$ of the set $V$ and the set $L$. $S_{V,L}=[s_{ij}]$ is a rectangular matrix of the type $m\times n$, or matrix has as many rows as there are peaks of the graph, and as many columns as there are graph arcs, where $s_{ij}=1$ if $(v_i, l_j)\in R$ and $s_{ij}=0$ if $(v_i, l_j)\notin R$ [8].

Graph G (Fig. 7a) can be defined with the incidence matrix of peaks and arcs. Let the set of peaks be $V=\{v_1, v_2,\ldots, v_m\}$ and the set of arcs $L=\{l_1, l_2,\ldots, l_n\}$. If the peak $v_i$ is adjacent to the arc $l_j$, then $s_{ij}=1$, otherwise $s_{ij}=0$. The relation R is defined as follows:

a. adjacent peaks at the same level are connected ($V_k^r \leftrightarrow V_{k+1}^r;\quad V_k^r \leftrightarrow V_{k-1}^r$)

b. adjacent peaks at the adjacent levels are connected, i.e. $\begin{pmatrix} V_k^{r+1} \leftrightarrow V_k^r; & V_k^{r+1} \leftrightarrow V_{k+1}^r; & V_k^{r+1} \leftrightarrow V_{k-1}^r \\ V_k^{r-1} \leftrightarrow V_k^r; & V_k^{r-1} \leftrightarrow V_{k+1}^r; & V_k^{r-1} \leftrightarrow V_{k-1}^r \end{pmatrix}$

where $V_k^r$ is the peak $k$ at the level $r$, $k = 0,\ldots, m$; $r = 0,\ldots, n$.

The incidence matrix of peaks and arcs of the graph is:

$$s_{kj}^{ri} = \begin{cases} i = r \wedge (j = k-1 \vee j = k+1), & \begin{array}{l} 1,\ \text{if arc } l_j \text{ protrudes from the peak } V_k^r \\ -1,\ \text{if arc } l_j \text{ enters in the peak } V_k^r \end{array} \\ i = r+1 \wedge (j = k \vee j = k-1 \vee j = k+1), & \begin{array}{l} 1,\ \text{if arc } l_j \text{ protrudes from the peak } V_k^{r+1} \\ -1,\ \text{if arc } l_j \text{ enters in the peak } V_k^{r+1} \end{array} \\ i = r-1 \wedge (j = k \vee j = k-1 \vee j = k+1), & \begin{array}{l} 1,\ \text{if arc } l_j \text{ protrudes from the peak } V_k^{r-1} \\ -1,\ \text{if arc } l_j \text{ enters in the peak } V_k^{r-1} \end{array} \\ \text{otherwise} & 0 \end{cases}$$

$$i = r-1, r, r+1$$
$$j = k-1, k, k+1$$

Therefore, the model of transport system of formed connections is described in this way, and according to them, of transport routes in the Primorje-Gorski Kotar County. However, if each branch of the graph is joined by a real number or weighting factor (distance, capacity, etc.), the graph is called a network. Defining and joining the appropriate weighting factors to each branch of the graph in Fig. 7 will be the subject of further study, whose settings are given in this paper.

## 5 Conclusion

In the end of 2010, new development of the Physical Plan of the PGKC began, which was necessarily preceded by the performance analysis of methodology for the development of the plan from 2000 based on the functional-nodal method. Fundamental characteristics of the method are related to the determination of focuses of development and to identification of the relationships between them. The conducted experimental studies showed that the transport network in the physical plans of counties can be derived in a quality way through this method. The sequence and scope of activities on the determination of the transport network was defined. Foremost is the traceability of the procedure for defining the system of connections from which the basic transport routes are then defined and which have to be established at the county level. It is necessary to say that the model itself is set so that the priorities are the ideal systems of connections the underlying transport routes are derived from. Based on the established transport routes the ideal network of roads is nominated by modes and it overlaps with the existing one as well as with the previously planned transport network. Based on this display the critical points of the system are determined, i.e. the optimal transport system of the studied area is identified.

It has been found that the presented model of establishing the system of connections and transport routes based on functional-nodal method fulfilled expectations and gave high quality results while allowing sufficient autonomy to local communities when developing physical plans of cities/municipalities. The above method is applicable to all strategic physical planning documents and presents a significant scientific and professional breakthrough in the area of transport and physical planning.

The paper proposes a model of the transport system of formed connections and according to them and transport routes in the Primorje-Gorski Kotar County, where basic principles of graph theory are used to define the connections according to the focuses of development or defining the transport network of desire lines. Further research will be based on the development of a model which would join each connection or a transport route a weighting factor which presents the road capacity, and to peaks or poles specific supply/demand, which would allow for obtaining an optimal schedule and ways to connect appropriate focuses of development.

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